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Examining changes in seafloor communities at the landscape scale around the Capricorn Bunker Group, Southern GBR

Holland, James W., Examining changes in seafloor communities at the landscape scale around the Capricorn Bunker Group, Southern GBR, Bachelor of Science (Honours), School of Earth & Environmental Sciences, University of Wollongong, 2015.
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Examining changes in seafloor communities at the landscape scale around the Capricorn Bunker Group, Southern GBR

Abstract
The aim of this honors project was to map changes in the sea floor communities at the regional scale within the Capricorn Bunker Group between the years of 2001 and 2014. The Capricorn Bunker Group is located at the southern end of the Great Barrier Reef near 30° south and 150° east and consists of 16 islands with 22 reefs, with 8 of these islands being vegetated and little in the way of topographic relief (Queensland Government, 2014).

This project accomplished its aim through a three stage method after the second set of benthic community ground coverage data had been gathered on the 2014 Joint Benthic Field & Remote Sensing Survey as undertaken by Sarah Hamylton et al (2014). Initially bathymetry DEM’s were created according to the method proposed in Stumpf & Holderied’s 2003 paper with minor adjustments based upon the source of the Satellite image. Then the reefs were mapped on the basis of their geomorphic zones as found via satellite images overlaid on top of bathymetry DEM’s in ARC Scene. The mapping allowed us to subsequently subsample the data on the basis of the desired geomorphic zone. Finally the change detection analysis was undertaken which uncovered a variety of results through the comparison of video records of benthic community ground cover. A wide variety of data was used in the project and this included bathymetry layers generated from satellite imagery, depth measurements photographs and video transects. A wide variety of community components were made available for study through the video surveys which included substrate type, the presence of hard alga and differing coral morphologies. Of these it was decided to focus on the hard coral branching and hard coral massive classes for their role in the reef building process and regional scale community formation. Between the 2001 and 2014 survey results with over 1500 points in the survey datasets with details of the field data collected can be found in Table 2 along with the sort of pre-processing that was undertaken.

In terms of general results most of the survey points experienced no change or some degree of growth over the survey period as seen in Figure 7. However it is to be noted that, that Figure 7 only serves as a relative indicator in terms of a positive or negative change in coral cover without taking into account the amount of change.

Change analysis revealed that the changes to the amount of hard coral cover were heterogeneous in their distribution with regards to each reefs geomorphic zones with the worst coral losses being sustained on the fore reef sections of most of the reefs with the reef flats and lagoons making nominal gains with a few exceptions. Overall 45% of the points showing a gain in coral cover, 37% of the points showed no change and 18% of the points showed a decline. Additionally in Figure 8 the declines, whilst outnumbered by the points that showed a gain in coral cover, were of a larger magnitude than most of the gains.

The scale of these changes in coral cover adds some additional context to the general change categories. The points experiencing losses typically could expect to experience losses of a greater size than the minor gains made by the other geomorphic zones leading to a potential net loss of coral cover.

On the reefs themselves some smaller scale trends were rendered visible. Whilst there were one or two exceptions the averaged change for the group as a whole ranged from negative four percent to positive four percent. At a broader spatial scale it was uncovered that most of the reefs whose fore reefs were experiencing losses were father away from the coast and could be divided from the fore reefs that were registering growth by a line trending North west to south east. Lagoons also exhibited this trend with the northwest to south east...
division with the losses being located mostly towards the coast. Additionally, it was observed that most of the losses were occurring on smaller hot spots of averaged coral cover.

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Sarah Hamylton

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University of Wollongong
School of Earth and Environmental Science

EESC 401 Outline of Honors Project

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Honors Title:

Examining changes in seafloor communities at the landscape scale around the Capricorn Bunker
Group, Southern GBR

A thesis submitted in part fulfilment of the requirements of the Honors degree of Bachelor of Science
in the School of Earth and Environmental Science, University of Wollongong 2015
Abstract:
The aim of this honors project was to map changes in the sea floor communities at the regional scale within the Capricorn Bunker Group between the years of 2001 and 2014. The Capricorn Bunker Group is located at the southern end of the Great Barrier Reef near 30° south and 150° east and consists of 16 islands with 22 reefs, with 8 of these islands being vegetated and little in the way of topographic relief (Queensland Government, 2014).

This project accomplished its aim through a three stage method after the second set of benthic community ground coverage data had been gathered on the 2014 Joint Benthic Field & Remote Sensing Survey as under taken by Sarah Hamylton et al (2014). Initially bathymetry DEM’s were created according to the method proposed in Stumpf & Holderied’s 2003 paper with minor adjustments based upon the source of the Satellite image. Then the reefs were mapped on the basis of their geomorphic zones as found via satellite images overlaid on top of bathymetry DEM’s in ARC Scene. The mapping allowed us to subsequently subsample the data on the basis of the desired geomorphic zone. Finally the change detection analysis was undertaken which uncovered a variety of results through the comparison of video records of benthic community ground cover. A wide variety of data was used in the project and this included bathymetry layers generated from satellite imagery, depth measurements photographs and video transects. A wide variety of community components were made available for study through the video surveys which included substrate type, the presence of hard aglae and differing coral morphologies. Of these it was decided to focus on the hard coral branching and hard coral massive classes for their role in the reef building process and regional scale community formation. Between the 2001 and 2014 survey results with over 1500 points in the survey datasets with details of the field data collected can be found in Table 2 along with the sort of pre-processing that was undertaken.

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The scale of these changes in coral cover adds some additional context to the general change categories. The points experiencing losses typically could expect to experience losses of a greater size than the minor gains made by the other geomorphic zones leading to a potential net loss of coral cover.
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Acknowledgements:
I would like to thank Senior Lecturer Sarah Hamilton and Phd student Stephanie Duce for their invaluable assistance in the generating and processing of the data required for this project without which the following would not have been possible.
**Introduction:**

Whilst the growing concern over the health of the Great Barrier Reef as impacted by climate change has led to an increased amount of research in this area this research has not had an even spatial distribution or focus across the highly variable local environments typically observed on coral reefs. For example, De'ath et al (2012, P947) examined declines in live coral cover estimating that the Great Barrier Reef had lost fifty percent of live coral cover since 1985. This project aims to expand such statements across a wider variety of geomorphic zones represented on reefs focusing on the Capricorn Bunker Group. It being a less studied southern portion of the 2,300 kilometer long Great Barrier Reef located approximately at 30° south and 150° east. This project aimed to calculate the change in cover percentages that have taken place in the benthic communities over the past twelve years (2001 - 2014) in terms of the geomorphic zones of the group in question. Additionally it also aims to see if there are any spatial trends in terms of gains or declines on the individual reefs or in the group as a whole.

The processes which go into shaping and forming the various geomorphic zones are divisible into the following three categories, tidal water level changes, wave energy regimes and sunlight constraints. Tidal energy plays an important role in the formation of reef flats and the infilling of lagoons through minimum tide levels and sediment transport. The reef flat marks the uppermost point of coral growth where the fatality rate due to exposure at low tide is balanced by the upwards growth of the reef. Once this equilibrium is attained the reef typically expands outwards. Tidal ranges also appear to play a role in the viability of reefs with reefs appearing to be unable to withstand tidal ranges of greater than 6 – 7 meters (Hopley, Smithers and Parnel, 2007, p 114 – 134). The next directive pressure on coral reefs is that of wave energy. This destructive force shapes the formation of the fore reef and algal ridge zones primarily through surge or wave action damage (Grigg 1998, p 263). It also influences the morphology of the corals present in the zones where wave action is greatest as branching corals are unable to cope with the forces involved in these areas. Sunlight in contrast to wave energy acts as a lower limiter on coral growth dictating the depth to which the fore reef can extend. The Zooanthellae’s requirement for sunlight restricts them and the reef building coral they inhabit to depths typically less than 30 meters (Guilcher 1988, p7).

Field data for this project was gathered between the 12th of May and the first of June 2014 on the Joint Benthic Field & Remote Sensing Survey in addition to a University of Queensland survey in 2001. A 3D bathymetry DEM was developed to assist manual digitization of the geomorphological zones (Fore reef, reef flat and lagoon) of the reefs in question. Once the mapping had been undertaken the benthic community data sets were created based on cover estimation from video transects with the 2001 hard coral cover percentages then being subtracted from the 2014 values to measure the change. It is hoped that the results from this project will improve our understanding of how the benthic communities of the Capricorn
Bunker Group are reacting to environmental change and so help to improve management decisions of this natural resource.

**Significance:**
With the Great Barrier Reef having lost 50% of its coral cover relative to the 1985 baseline (De'ath et al 2012, P 947), enhancing our understanding and correcting the gaps in the scientific knowledge pertaining to the Great Barrier Reef particularly inshore reefs such as the Capricorn Bunker Group, is of paramount importance. Also of concern is increasing disease prevalence and hampering reef health through increased turbidity (Hughes et al, 2003). These coral cover losses and continuing climate change are causes for concern considering the small amount of research that has been done upon the study area specifically, excluding the research done on One Tree Island and Heron Island which is highly localized.

As such, this research would go some way toward rectifying this lack of broader geographical enquiry with regards to benthic community change for the Capricorn Bunker Group. The targeted communities in this project are the communities which constitute the coral reefs of the islands. This project aims to grant us a greater understanding of how the GBR is being affected by climate change and other threats such as the crown of thorns starfish, bleaching events, commercial fishing as mentioned by Bohensky et al (2009, p 877) on a more local scale. This is particularly relevant considering that fact that the rate of sea surface warming is higher in the southern GBR than in the north (Woolsey at al 2012, p 749).

This study's results will help to track the rate of habitat and community shift as a result of climate change and could serve to assist in further management decisions for the Great Barrier Reef and Marine Park through the elucidation of any local or larger scale trends in community change through the Capricorn Bunker Group.

**Aim:**
This project is designed to uncover the degree of and direction of change in the benthic communities of the Capricorn Bunker group over the twelve year period between 2001 and 2014 as a result of environmental change. This was done via the comparison of the 2001 and 2014 benthic community survey results with over 1500 points of video snapshots in total, 465 of these points were repeat visit points which could be used for the change analysis. Other data used in the project include bathymetry layers generated from satellite imagery and depth readings taken from a single beam echo sounder. The Capricorn Bunker Group is located at the southern end of the Great Barrier Reef near 30° south and 150° east. Whilst a large amount of research has been conducted upon the Great Barrier Reef to track sea floor community change little has been done on the Capricorn Bunker Group reef and has been restricted to the reef slopes.
Objectives:

1. Quantify the percentage change in the communities that make up the sea floor at the regional scale for the Capricorn Bunker Group.

2. Inter-reef comparison and across geomorphic zones within the reef platform communities.

3. To examine these zones and note any changes or spatial trends that have occurred over the past twelve years.

Research to date:

The Great Barrier Reef and Capricorn Bunker Group:
This review will introduce the context of both the Great Barrier Reef and that of the Capricorn Bunker Group, then go onto review the literature to date. Subdividing research to date into the following categories; biology of the group, geology, climate change, threats to the Great Barrier Reef (and the Capricorn Bunker Group) and research done to date specifically on the Capricorn Bunker Group itself. Following this will be a short section on change detection techniques and methodologies.

Geology of the Great Barrier Reef and Capricorn Bunker Group:
In order to understand the significance of this project and its relation to the existing body of research the context of the Capricorn Bunker Group within the Great Barrier Reef (GBR) must be examined. In terms of its physical scale which is depicted in Figure 1 the GBR is unrivalled. The Great Barrier Reef Marine Park Authority states that it is approximately 2,300 km long, with a width of 60 to 250 km and having an average depth of 35 m. According to De'ath et al (2012, P 947) and the Great Barrier Reef Marine Park Authority 2014 it is made up of approximately 3000 coral reefs, 600 continental islands and several hundred coral cays.
The Capricorn Bunker Group itself is set in the southern end of the Great Barrier Reef and consists of 16 islands with 22 reefs, with 8 of these islands being vegetated and little in the way of topography (Queensland Government, 2014). They came to the notice of Europeans in the Journals of Captain Cook as he sailed through the area in the year 1770 (Australia National Library, 2004). Physically speaking, the group consists of four reef types classified by Maxwell (1968) as lagoonal, elongate platform, platform and closed ring reefs see Flood, (1977, P 967).

Various studies such as that done by Anderson et al (2011, P 979), have found that the sea floor type and topography have a huge bearing on the type of communities that will develop with areas of increased rugosity. Examples of this being the association between hard substrates and raised topography and abundance for sea floor communities (Pittman et al 2010, P 10) and (Emslie et al, 2010).

**The Biology of the Great Barrier Reef and the Capricorn Bunker Group:**
In terms of their biology both the GBR and Capricorn Bunker Group are of note with the GBR as a whole being one of the global hot spots of biodiversity and the Capricorn Bunker Group being crucially important in the life cycles of a variety of faunal species. Two examples of such species are green turtles which use some of the islands for breeding and
Wedge tailed Shearwaters using the Group as a breeding center for an estimated 70% of their population (Queensland Government, 2014) and (Booth, 1970).

What studies have been done have focused on the flora or avian fauna present on land or have been confined to Heron or One Tree islands. The studies that have been done that are relevant to the focus of the proposed honors have been done in reference to the Great Barrier Reef as a whole or with a focus on other international locations. According to the data provided by the Queensland Government on their "About Capricornia Cays 2014" website the group is home to a wide variety of birds and plays an important role in their life cycles as evidenced by the dependence of 70% of the NSW Wedge tailed shear waters population upon these islands for breeding. Booth (1970) examined the bird species present on the group over the course of the study as reported by volunteers. In terms of the floral research Rodgers and Morrisons' 1994 report focused on species occurrences both native and alien.

Climate Change:
Whilst a large amount of research of all kinds has been done on the GBR as a whole there is relatively little that has been done on the changes in seafloor communities at the landscape scale around the Capricorn Bunker Group, which is what this project would attempt to rectify. This is surprising considering the higher rate of warming in the southern portions of the GBR and the accessibility of this region (Woosley et al 2012, P 794) and the impacts that this will have on the sea floor communities. The research to date is best divided into three categories which are threats to the GBR as a whole, Geological research, biological research and the work done on tracking sea floor community changes using GIS.

Whilst the Capricorn Bunker Group as a whole has had little work done on it, there has been a good amount of research done has been done on Heron and One Tree Islands. This research has been subdivided according to areas pertaining to this study. Carbonate production for the One Tree Island was studied by Doo, Hamylton and Byrne, (2012), and Hamylton, et al., (2013). A study by Scopelitis, et al., (2011) examined how colonization rates of coral have responded to sea level changes and overall rise over the past 35 years with the finding that the sea level rise itself does not appear to have harmed the reefs at Heron Island. This was accomplished by using channels as surrogates for changes in sea level rise. In addition to this, several studies such as Phinn, et al., (2012), Roelfsema, et al., (2006) and Joyce, et al., (2004) studied methods of mapping coral reefs as well as benthic survey techniques.

Due to the amount of work that has been done on climate change the nature of the threats are well known. The primary threats were identified as overall climate change, acidification, worsening water quality, destruction of coastal habitat, crown of thorn star fish and fishing, both industrial and traditional (Bohensky et al 2011). De'ath's 2012 study which used sites from the AIMS long term monitoring program that focused on the fore reef noted that overall coral cover in the GBR had declined by around 50% with 66% of this decline occurring since 1998.
<table>
<thead>
<tr>
<th>Threats to the Great Barrier Reef:</th>
<th>Summary:</th>
<th>Sources:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crown of Thorns Starfish</td>
<td>● Crown of thorns star fish thought to be responsible for roughly 40% of reef loss referring to De'arth et al, 2012. ● Fishing has removed predators and combined with excess nutrient runoff for larval stage food has led to population explosions.</td>
<td>● Voler et al., 2008. ● Lamare et al., 2014. ● Fabricus et al., 2010 ● Brodie et al., 2005</td>
</tr>
<tr>
<td>Water Quality</td>
<td>● High water clarity must be present for there to be richness in hard coral species.</td>
<td>● De’Ath and Fabricius, 2010 ● Sweatman et al., 2011 ● Brodie et al., 2005 ● De’Ath et al., 2009</td>
</tr>
<tr>
<td>Coral Bleaching</td>
<td>● Being exposed to the air due to extreme winds and storms can lead to bleaching and a decrease in live coral cover. ● 42 % bleached slightly in 1998 increasing to 54% during the 2002 bleaching event.</td>
<td>● Hoegh-Guldberg, 2005 ● Woolsey et al, 2012 ● Berkelmans, et al., 2004, P 74</td>
</tr>
<tr>
<td>Increasing sediment load</td>
<td>● Increases bio-erosion and the turbidity of the water slowing growth rates, and smothering the coral ● Reduced biomass of planktovorius fish and light levels</td>
<td>● Johansen and Jones 2013 ● Fabricus, 2005.</td>
</tr>
<tr>
<td>Tourism</td>
<td>● Damage to coral through removal and foot/boat traffic</td>
<td>● Sarmento and Santos, 2012.</td>
</tr>
</tbody>
</table>

Table 1: Table outlining the major threats to the Great Barrier Reef.

Reef Environments:
In addition to the research on the impacts of climate change other workers in the field have focused upon the geological and biological characteristics of the Group. The group is thought to have begun its growth during the early Pleistocene according to Jell and Flood 1978.
Research done by Flood, (1977) referring to Maxwell, (1968) viewed the reefs as belonging to the four following classes: they being lagoonal, platform, elongate platform and closed ring. Maxwell (1968, P 151) considered the Bunker Group distinct from the Capricorn group as being a dispersed shelf edge reef which Figure 1 matches. As a whole the reefs were considered to be made up of an algae rim, coral zone and sand which matches a cursory visual examination of Figure 5. Structurally Marshall and Davies (1981, P 953) referring to Davies et al, (1977a) found that most of the Capricorn Bunker Group reefs were steeper on their windward sides with the gentle gradients found on the leeward sides of the reefs. The sediments as noted by Maxwell (1968, P 192 - 216) were found to be both of biotic and a biotic nature. The biotic sediments were sourced from past and existing forams and fauna and the abiotic sediments being terrigenous in nature sourced from the coastal areas.

Asides from the research done to date on the "micro" scale geological characteristics of the group other authors have looked at the larger scale aspects of the target group. Davies et al, (1981) mentions seismic and resistivity studies done by other workers in the field to study the sub floor structures. The other mesoscale area of focus was that of the Capricorn Eddy as studied by Weeks et al, (2010) and Mao and Luick, (2014) who attempted to study its formation and flow patterns as influenced by the shelf via high frequency radar and other methods.

Increasingly GIS tools have allowed studies to be undertaken at greater scales and to predicatively map of habitats with inferred sea floor community presence as shown by Urbanski and Szymelfenig (2003, P 99), Mellin et al (2010, P 212) and Duce et al (2014). The second way in which they aided reef based research is through enhancing our understanding of the relationship between sea floor substrate type and their associated sea floor communities.

**Change Detection Techniques:**

In order to gain any understanding of how the Great Barrier Reef is reacting to the changing environmental conditions a variety of change techniques were developed over time due to the difficulty of comparing against older historical records (Sweetman et al, 2011). Broadly speaking these can be divided into transects, visual mapping via aerial and satellite images, and statistical methods of measuring change.

Transects as used by Sweatman et al, (2008) offer a cheap method of change detection for small areas which is easily implemented and readily understood by volunteers. Whilst they may not be suited for rapid repeat surveys of large areas they are useful by way of providing a reliable baseline for future studies as well as acting as ground trothing for more advanced methods of change analysis. In the case of the AIMS (Australian Institute of Marine Science) boat based Manta Tow transect surveys are used to monitor live and dead coral cover, crown of thorns starfish population levels and fish populations on a yearly basis (Sweetman et al 2008, P 35). While most transects are undertaken via scuba gear or boats they can also be based within aircraft (Stoddart and Johannes 1978, P 17.) Transects typically use still images or video cameras for data capture or have their data recorded into workbooks by the scuba diver.
Whilst the visual interpretation of changes may be the oldest method of change detection it has remained relevant through the improvement of image processing techniques and increasing spatial and temporal resolutions of image capture. As environment change has accelerated and the size of areas being surveyed increased new techniques were required to overcome the inefficiencies of traditional visual surveys.

As the processing capabilities of computers have increased algorithms have increasingly become a viable tool in image analysis with the aim of detecting change in the environment. One of the primary developments in terms of change detection through images would be the development of algorithms such as Fuzzy Logic Classifiers (Lesser and Mobley 2007, P 820), change vector analysis (Michalek et al, 1993) and neural networks. These methods have advantages over manual examination in so far as spectral pixel bleed (Ghosh Mishra and Ghosh 2011, P 713) and salt and pepper artefacts are concerned (Blaschke 2010, P 4 referring to Xie et al 2008).

Methods:
This project's aim will be achieved through three stages.

- **Stage one**: Generate Bathymetry DEMS for each of the reefs involved in the study developed by Stump et al with minor adaptations depending on the type of satellite image used.

- **Stage Two**: Map the geomorphic habitats of the reefs through direct visual interpretation of the images with a bathymetry model displayed in Arc Scene assisting in the mapping.

- **Stage Three**: Compared field data sets the two benthic community surveys and computing the change statistics by combining the hard coral cover classes and then subtracting the 2002 cover percentages for the aforementioned class from the 2014 cover percentage values. Once the change percentages had been computed, the change percentages were examined on the basis of the geomorphic zones to see if there were any trends across the reefs. Additionally positional accuracy of the 2014 surveys compared to the areas sampled by the 2001 survey was examined through the comparison of the GPS position for the 2014 field survey, taking into account the accuracy of the GPS unit, and the field of view covered by the respective 2001 field survey point.
Figure 2: Flow chart showing the major conceptual stages of the method utilized for this research.

Bathymetry DEM
- Satellite Image
- Depth Measurements

Mapping of Geomorphic Classes
- Geomorphic class shape files
- Bathymetry DEM
- Satellite Images

Change Detection:
- 2001 and 2014 Benthic community cover percentages
- 2014 Coral Cover change measurements
- Spatial analysis

Post-processing adjustments:
- Sound speed profile
- Tidal variation
- Target angle calculations

Processing of temporal, spatial and spectral variation in the signal:
- Survey line mosaic
- Bottom deflection
- Cross section graphs
- Surface models
**Data Acquisition:**
It is to be noted that the author of this thesis did not participate in the gathering of the field data itself and was involved only with the processing of the data for the thesis report, and its writing.

**Surveys Prior to Change Analysis:**
The change analysis of this project is based upon two surveys which were undertaken in the years 2001 and 2014. The 2001 study was undertaken by Joyce et al (2004). The 2014 study was undertaken by Hamylton et al (2014b).

In terms of methodology, the 2001 survey utilized boat based transects capturing data via a two sided image taken of the corals beneath the boat with fifty meter spacing between survey points. This survey transects ceased when either visibility or depth prevented further progress and data capture (Joyce et al 2004, p21). Once the data had been captured a twelve point grid was overlaid to assist in the calculation of percentage ground cover Kohler, K. E., & Gill, S., M., 2006). K means clustering was also utilized in order to find areas with similar substrates.

The survey undertaken by Hamylton et al (2014) utilized a variety of methods for field data capture as it was undertaken as a collaborative effort between the universities of Wollongong, Sydney and Queensland. The primary method which is of interest to this project were the oblique video transects followed by the boat integrated GPS and echo sounders. These transects involved the camera being lowered down and being allowed to drift behind the boat for around thirty seconds with GPS being used for positional accuracy (Hamylton, 2014b).
**Data Types used in this study:**

<table>
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<th>Field data collection 2002</th>
<th>Field data collection 2014</th>
<th>Field data analysis</th>
<th>Image type</th>
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<td></td>
<td>Photo transects (### photos, total distance, # transects)</td>
<td>Drop camera</td>
<td>Bathymetry</td>
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<td>500</td>
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<td>Bolt</td>
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<td>Hoskyn</td>
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<td>Llewellyn</td>
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<td>Heron</td>
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<td>Oct-Nov 2014</td>
<td>51</td>
<td>Oct-Nov 2014</td>
</tr>
<tr>
<td>Maidhead</td>
<td>yes</td>
<td>537, 1230 m, 4 tr</td>
<td>52</td>
<td>non</td>
</tr>
<tr>
<td>Polmaise</td>
<td>yes</td>
<td>250, 1000 m, 3 tr</td>
<td>70</td>
<td>non</td>
</tr>
<tr>
<td>Northwest</td>
<td>yes</td>
<td>1424, 4500 m, 6 tr</td>
<td>114</td>
<td>non</td>
</tr>
<tr>
<td>North</td>
<td>no</td>
<td>32, 65 m, 1 tr</td>
<td>33</td>
<td>non</td>
</tr>
<tr>
<td>Tryon</td>
<td>yes</td>
<td>480, 1550 m, 4 tr</td>
<td>52</td>
<td>non</td>
</tr>
</tbody>
</table>

Table 2: Data types used in this project as sourced from Hamylton et al’s 2014 “Fieldwork Report: Joint Benthic & Remote Sensing Survey”.

Once the data had been gathered evaluation was required of the various options for geomorphological habitat mapping. The main criteria for our testing were that it must be low cost both in terms of time and finances without requiring new hardware purchases, easy to use and be able to be used by someone with little familiarity with the target area.

**Stage One: Generation of the Bathymetry DEM Model**

The process used to generate the Digital Elevation Model was the same as used by Stumpf and Holderied (2003). This band ratio approach is more accurate than the alternative linear method and used the rate of attenuation of the blue/green bands for satellite images, in conjunction with depth measurements in order to estimate depth for the whole image coming from a single beam echo sounder data. World view Two images required the use of bands one and three in order to produce acceptable results and so make use of its coastal blue band (insert reference here).

The required bands had their natural logs calculated before being ratioed by dividing band one by band two for Ikonos and Geoeye and band 1 and band three for World View images. Once this had been done the log value for each point was added to the Sonar points attribute table alongside Z (representing depth) values. This table that defined the relationship between depth and the log ratio of the satellite image wavebands was then exported to excel where a
scatter graph was created displaying the second order polynomial equation representing the data and the $R^2$ squared value. Once that step had been accomplished the polynomial equation was then copied back into Arc Gis's raster calculator to produce the DEM from the aforementioned image.

![Graph](image_url)

Figure 3: Plot of band ratio against measured depth as part of the Digital Elevation Model production.

**Stage Two:**
This stage involved manual inspection of the satellite image and digitizing the detected geomorphological zones with the assistance of the Bathymetry DEM in Arc Scene after having decided upon the geomorphic classes to be mapped. This was done at a scale of one to six thousand for all of the coral reefs and an arc scene vertical exaggeration of thirty times. The geomorphological classes being mapped were decided on a reef to reef basis. The definitions for the geomorphological classes were drawn from the Modern Encyclopedia of Coral Reefs and consultation with Sarah Hamylton.

**Geomorphological Zones classification Scheme:**
In order to grant our change analysis results a degree of spatial context in terms of each individual reef and to aid in the comparison of change statistics between reefs a geomorphological classification scheme had to be developed for this project. Classification schemes utilized by Hopley (2011) and that of Guilcher (1988) were compared and then adapted to the Capricorn Bunker Group in Consultation with Sarah Hamylton's own experience with the group. After comparison of the two aforementioned schemes and consultation it was decided that the Algal ridge, fore reef, reef flat and lagoon classes were to
be used with the criteria adapted to the study site. Following the examination of the chosen characteristics of each class the forces and processes which go to shape these zones will be covered.

The Algal rim or ridge as it is sometimes known was a zone acknowledged by both of the works studied. The definition which most shares the greatest number of commonalities between the two is that an Algal Ridge is a physical structure built out of the agglomerated forms of massive or encrusting algal and some corals that is normally found on the windward rather than lee ward side of the reef. This is the case as they are better able to withstand the wave energy environment due to their stocky or encrusting form. Whilst a separate class was used for the algal ridge in Hopley’s (2011, p79) work it was of a grouped class in Guilchers (1988, p16) book. Based on this academic definition the Algal ridged for the Capricorn Bunker Group were mapped on the basis of the following criteria; mainly that they were located on the windward side of the reefs in question, they correlated with darkened lines which followed the join between fore reef and reef flat classes and that they were located in the area where waves were breaking upon the reef. This area is to be found between 1300 meters and 1400 meters in Figure 4.

The next geomorphic zone that was used in our classification scheme was the Fore Reef Class with its criteria based on examination of Hopley’s (2011) and Guilcher’s (1988) works. The fore reef zone was jointly defined as an area which sloped predominantly towards the ocean which can on occasion reduce its gradient to such a degree as to form terraces or platform like structures. This zone is generally home to large amounts of living coral with species and morphology varying with depth. As far as the key criteria for the mapping undertaken as a part of this research project the fore reef was considered to the area bordering the reef flat whilst still connected of on close proximity to the reef flat on the ocean side with a slope away from the reef flat which generally increases with depth. This corresponds to the section of the Northwest Reef cross section between 1400 meters and 2000 meters.

The second last of the two geomorphic zones is the reef flat which is the section of the reef cross section between six hundred meters twelve hundred meters. Spatially it is the area enclosed by the fore reef with little to no variation in its topography and is the widest flattest part of the reef according to Guilcher, (1988, p25). Hopley, (2011, p 869) noted two main classes which they can be typically divided into two classes, they being rubble dominated reef flats and coral dominated reef flats. In terms of your own classification scheme it was decided to agglomerate these classes into a single reef flat class and that it was best defined as the area encircled by the fore reef and algal ridge zones with a steady depth across the area.

The Lagoon was the simplest class in terms of its mappable characteristics and is represented by the naught to five hundred meter section of the cross section below. As defined by Hopley (2011), a lagoon is a depression or a spot of greater depth on a reef which can be entirely surrounded by the reef flat and fore reef, although channels may exist which allow water exchange with the ocean. Our own mapping guidelines closely followed this definition with
the additional caveat that there is typically a sharp, relative to the preceding areas, increase in depth as you cross over the edge into the lagoon.

Figure 4: Depth Cross section of Northwest Reef starting in the lagoon and extending to the fore reef with map showing the start and end locations of the transect below.

**Geomorphic Mapping Methodology Comparison:**
In order to decide upon which mapping approach to use four alternatives were tested upon the Lady Musgrave Island. The mapping was done via geomorphological zones so as to facilitate the subdivision of the change detection statistics. Prior to the mapping of the test site some research was required for definitions for each of the habitat zones. The following zones were selected for mapping: The Island, Lagoon and patch reefs, Fore reef, reef flat and algal ridge.

The three methods tested were direct visual interpretation, bathymetry assisted - direct visual mapping and finally the supervised maximum likelihood algorithm. Scale played a key role in the two approaches which did not use an algorithm with the scale for the digitization being one to six thousand.

**Direct Visual Interpretation:**
Of the three methods chosen for evaluation the direct visual approach was both the simplest and cheapest both in terms of financial costs and in terms of time required. The procedure for
this approach was to zoom into the provided image to about a 1:6000 scale. Once this had been done the varying geomorphic zones were then mapped. This approach was not without its problems however. One example of the issues encountered was deciding when patch reefs were located in the lagoon or on the sand of the reef flat. Another issue being differentiating between the hard substrate portion of the reef flat on the southern side of the island and hard rubble that was a part of the lagoon floor in the same area. Finally a familiarity with the area of research and the geomorphological habitats being mapped is required otherwise accuracy may be hampered.

**Bathymetry Assisted:**
Considering the flaws of the direct visual classification approach this approach was chosen as one of the test candidates in an attempt to compensate for them. Absolute accuracy was not required for this DEM as it was only used to indicate relative differences in depth.

The bathymetry layer was created through the ratio method described by Stumpf and Holderied (2003). It was chosen over the linear approach as it was able to provide better depth penetration by five to ten meters and did not require dark water subtraction (Stumpf and Holderied, 2003 P554).

Whilst visual classification or digitization still took place at the same scale, Arc Scene was used to create a 3d image of the island; this allowed enhanced accuracy in areas where depth was a key characteristic of the respective geomorphic habitats such as those areas of difficulty mentioned above. Similar to the direct mapping approach this method is low cost and did not require a large amount of time. In closing this approach still suffers from errors brought about by a lack of familiarity with the area and these can be compounded by inaccuracies in the bathymetry layer which can be traced to errors due to the coefficients used, spatial resolution of the base image and atmospheric interference or water turbidity.

**Supervised Maximum Likelihood Classification:**
The supervised maximal likelihood algorithm was the final test candidate. It was selected as with proper training area selection and sufficient layers fed into the algorithm it can achieve good levels of accuracy. During the course of testing 5 training areas were selected for each class, these were then fed into the algorithm alongside the base image and the generated bathymetry layer. Whilst this approach did have improved accuracy compared to the other two approaches for certain classes such as the lagoon and algal ridge it was unable to map the channel and sporadic spur and grove classes. Generally it was found the smaller the class the worse the accuracy was.
Stage Three: Joining, change detection and testing for Trends

For this final stage of the methods the steps can be subdivided into two sub stages. The first concerning the joining of the attribute tables and computing the measures of change. The second being examining the data for trends.

**Stage Three A:**

For each of the reefs both the 2002 and 2014 points were added to ArcGIS table of contents and were joined. Once this had been done change columns were added for each of the benthic community classes and the coverage percentages of the 2002 data set were subtracted from the 2014 data sets coverage percentages. Additionally the hard coral massive and hard coral branching classes for each of the two measurement periods were added together in each of the respective years before having the 2001 total subtracted from the 2014 total giving a total change measurement for the combined hard coral benthic communities.

**Stage Three B:**

Once the change measures had been calculated they were then examined as a whole followed by per geomorphic zone with the geomorphic zone change results being compared against other reefs results for the same zone that were studied within the group. The dataset was subdivided by spatial query using spatial query based on the geomorphic zones. In all cases the mean rate of change and its direction were noted in addition to the statistical deviation for each grouping of points. These statistics were used to generate a variety of graphs and figures as seen in the results section.

---

*Figure 5: Three case maps show the three methodologies used to map Lady Musgrave Island. In order the pictured depict direct visual mapping, bathymetry assisted and finally supervised maximal likelihood.*
Of the total number of survey points available from the combined 2001 and 2014 surveys only four hundred and sixty five of these were close enough to one another to allow meaningful change detection. A select by location was performed to limit the pool of survey points to those that were in close proximity to one another with a mean distance of

**Results:**

The main areas covered by the results section are the distribution of the change detection analysis results in terms of the nature of the change, the spread of these changes in terms of the size of the change in groundcover, how these changes vary across the reefs, and geomorphic zones and finally any spatial trends noticed.

**Stage One:**

**Bathymetry DEM Accuracy Check and Modelling:**

As a part of this change analysis project, mapping of the geomorphic zones was undertaken with the assistance of a 3D Digital elevation model. In order to ensure the accurate spatial representation of the geomorphic zones of the reefs and so the validity of any trends we perceive in the change analysis a two stage accuracy check was undertaken.

The two stage accuracy check first involved comparing the modelled depths against the calibration subset of depth measurements, the results of which can be seen in the calibration graphs below with the average R² value being 0.85. Some manual editing out outlying points was undertaken to improve the accuracy of the model where the R² value was deemed too low.

The second stage of the accuracy check was undertaken after the DEM had been produced. This involved comparing the modelled depth points against the Validation subset of the measured depth points which went on to have an average R² value of 0.83. Overall the R² values ranged from a low of 0.56 through to 0.94 with the averages for both calibration and validation residing in the mid 80’s percentage wise.

<table>
<thead>
<tr>
<th>Location</th>
<th>Calibration R²</th>
<th>Validation R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyrion Island:</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td>North West Island:</td>
<td>0.68</td>
<td>0.69</td>
</tr>
<tr>
<td>One Tree Island:</td>
<td>0.93</td>
<td>0.93</td>
</tr>
<tr>
<td>Sykes Reef:</td>
<td>0.83</td>
<td>0.82</td>
</tr>
<tr>
<td>Heron Island:</td>
<td>0.83</td>
<td>0.82</td>
</tr>
<tr>
<td>Wistari Reef:</td>
<td>0.92</td>
<td>0.92</td>
</tr>
<tr>
<td>Lamont Reef:</td>
<td>0.87</td>
<td>0.86</td>
</tr>
<tr>
<td>Fitzroy Reef:</td>
<td>0.94</td>
<td>0.94</td>
</tr>
<tr>
<td>Polmaise Reef:</td>
<td>0.59</td>
<td>0.56</td>
</tr>
</tbody>
</table>

*Table 3: R² values for both the calibration and validation plots created during the bathymetry DEM generation.*
Table 4: 3D image of Tyrion reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.

Tyrion Reef:

Calibration:

Validation:

\[ y = -1859.4x^2 + 4122.9x - 2286.2 \]
\[ R^2 = 0.9252 \]

\[ y = 0.0109x^2 - 1.1244x + 0.0114 \]
\[ R^2 = 0.9391 \]
Table 5: 3D image of Northwest Island and reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 6: 3D image of One Tree Island and reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 7: 3D image of Sykes reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.

\[ y = -1504.6x^2 + 2774.2x - 1279.6 \]

\[ R^2 = 0.9316 \]

\[ y = 1.01x - 0.0331 \]

\[ R^2 = 0.93 \]
Table 8: 3D image of Heron island and reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 9: 3D image of Wistari reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 10: 3D image of Lamont reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 11: 3D image of Fitzroy reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 11: 3D image of Masthead island and reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Table 12: 3D image of Polmaise reef presented alongside the layer ratio vs measured depth and modeled depth vs validation depth points.
Stage Two:

Figure 6: Geomorphic classifications of the Capricorn Bunker Reefs, derived from visual interpretation of high resolution satellite images and digital elevation models.
**Stage Three:**

Figure 7 shows the distribution of the change analysis results in terms of the categories of growth, no growth and decline. Of the four hundred and sixty five points two hundred and eight or 45% registered in the growth category. One hundred and seventy five or 37% points were within the no growth category and eighty two points or the remaining 18% showed a decline.

---

*Figure 7: Distribution of field survey points as per the nature of their change without taking the size of change into account.*
Figure 8a and Figure 8b depict first the spread of the points that registered in the growth category of Figure 7 and secondly those that registered declines in terms of the size of the change registered. The graph illustrating the spread of the growth points had most of its points (84%) located in the categories showing twenty five percent growth or less with an average growth rate of roughly fifteen percent. Figure 8b depicts the spread of the points that registered a decline in hard coral cover and has most of its points in the first three categories or 86% with an average decline of twenty five percent.

What is more important than the distribution of the points in terms of the direction of change is the distribution of the scale of the change shown by the two bar graphs in Figure 8 and their location on the reef in terms of its geomorphic zones. A cursory examination of these two graphs reveals that in terms of their relative proportions of their own totals the bottom declines graph has far more points in the categories denoting declines of twenty five percent and above. The fifty to seventy five percent and seventy five to ninety six percent categories in the declines graph contains three to four times the relative amount of points in the same category in the upper growth graph.

Figure 8: Distribution of the magnitude of the changes in benthic communities with the top graph depicting the spread of the positive changes and the bottom the negative.
This next section showcases the basic statistics per reef and per geomorphic zone for each of the reefs with Table 6 showing the results averaged per geomorphic zone per reef.

### Hard Coral Combined Change:

<table>
<thead>
<tr>
<th>Reef:</th>
<th>Max:</th>
<th>Min:</th>
<th>Mean:</th>
<th>Standard Deviation:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyrion Island:</td>
<td>31.6%</td>
<td>-36.6%</td>
<td>-3.3%</td>
<td>15.2</td>
</tr>
<tr>
<td>North West Island:</td>
<td>30%</td>
<td>-50%</td>
<td>3%</td>
<td>10.7</td>
</tr>
<tr>
<td>Sykes:</td>
<td>55%</td>
<td>-45%</td>
<td>2.1%</td>
<td>14.7</td>
</tr>
<tr>
<td>Heron Island:</td>
<td>47.5%</td>
<td>-95.8%</td>
<td>-3.6%</td>
<td>30.5</td>
</tr>
<tr>
<td>Wistari:</td>
<td>45%</td>
<td>-52%</td>
<td>4%</td>
<td>16.8</td>
</tr>
<tr>
<td>One Tree Island:</td>
<td>75%</td>
<td>-75%</td>
<td>11.9%</td>
<td>25.4</td>
</tr>
<tr>
<td>Polmaise:</td>
<td>90%</td>
<td>-4.2%</td>
<td>4.5%</td>
<td>16.2</td>
</tr>
<tr>
<td>Masthead Island:</td>
<td>71.7%</td>
<td>-76.7%</td>
<td>3.4%</td>
<td>17.3</td>
</tr>
<tr>
<td>Lamont:</td>
<td>10%</td>
<td>-62%</td>
<td>-2.7%</td>
<td>12.3</td>
</tr>
<tr>
<td>Fitzroy:</td>
<td>55%</td>
<td>-70%</td>
<td>-2%</td>
<td>26.0</td>
</tr>
</tbody>
</table>

*Table 14: Showing the minimum, maximum, mean and standard deviation measurements for the rates of change for each of the reefs as a whole.*

Figure 10 shows the average change for the three geomorphic zones used in the change analysis process. Of the three zones the lagoons had the highest average rate of growth followed by the reef flats, with the fore reefs hard coral cover average being a decline.

![Figure 10: Average change magnitudes per class averaged across all reefs mapped during this project for the hard coral cover combined class.](image)

This final table focuses on the average change rates per geomorphologic zone per reef with the averages being calculated on this basis. Most of the Fore reefs experienced declines with increases being
primarily found on the Reef flat. The Lagoon class experienced growth on half of its points with the two lagoons experiencing declines.

Hard Coral Averages per Geomorphic Zones:

<table>
<thead>
<tr>
<th>Reef:</th>
<th>Fore Reef:</th>
<th>Reef Flat:</th>
<th>Lagoon:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tyrion Island:</td>
<td>-5.3%</td>
<td>1.9%</td>
<td>NA</td>
</tr>
<tr>
<td>North West Island:</td>
<td>-5.8%</td>
<td>5.8%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Sykes:</td>
<td>-1.9%</td>
<td>3.4%</td>
<td>NA</td>
</tr>
<tr>
<td>Heron Island:</td>
<td>-18.6%</td>
<td>4.9%</td>
<td>NA</td>
</tr>
<tr>
<td>Wistari:</td>
<td>3.0%</td>
<td>8.1%</td>
<td>-6.8</td>
</tr>
<tr>
<td>One Tree Island:</td>
<td>16.0%</td>
<td>0.5%</td>
<td>NA</td>
</tr>
<tr>
<td>Polmaise:</td>
<td>3.4%</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Masthead Island:</td>
<td>-26.1%</td>
<td>10.1%</td>
<td>33.0%</td>
</tr>
<tr>
<td>Lamont:</td>
<td>-12.6%</td>
<td>-0.1</td>
<td>NA</td>
</tr>
<tr>
<td>Fitzroy:</td>
<td>1%</td>
<td>-1.2%</td>
<td>-5.9%</td>
</tr>
</tbody>
</table>

Table 15: Mean change rates per reef per geomorphic class for the reefs surveyed.

Similar to the heterogeneity of the change statistics per geomorphic zones per reef, the change analysis revealed broader spatial trends that were also heterogeneous in nature. The losses as averaged for the fore reef zone were confined to the “outer” reefs. The reefs whose fore reefs experienced increases when averaged were confined to the south west with the exception of Fitzroy reef. The losses were located mostly on the smaller hot spots of coral cover as noted by the background average layer.

An examination of the regional spatial context of our results is facilitated by the following Figures 12 through to 15. Figure 12 shows the averaged change results for the fore reefs as overlaid on the average coral cover between 2001 and 2014. The losses were primarily concentrated on the reefs closest to the outer shelf whose location relative to the group can be seen in Figure 1. In this Figure the only reefs whose fore reefs experienced an increase in coral cover were those three located closes to the shoreline and Fitzroy.
Figure 12: Averaged change results for each of the reefs or islands that had their fore reefs surveyed overlaid on top of an averaged hard coal cove layer with the Capricorn Bunker Group as a whole in the inset image relative to the coast.
In contrast to the results displayed with the previous fore reef Figure, the growth categories for the reef flats were located mainly to the north west. Those reefs whose reef flats were registering on average a decline were confined to the center and south east.

*Figure 13:* Averaged change results for each of the reefs or islands that had their reef flats surveyed overlaid on top of an averaged hard coal cover layer with the Capricorn Bunker Group as a whole in the inset image relative to the coast.
Of the four lagoons that were surveyed the two reefs whose lagoons registered on average growth were located in the northern hemisphere between 300º and 120º.

*Figure 14: Map showing the averaged change results for each of the reefs or islands that had their lagoons surveyed overlaid on top of an averaged hard coal cover layer with the Capricorn Bunker Group as a whole in the inset image relative to the coast.*
**Discussion:**
The change analysis performed as a part of this project aimed to expand existing research on the Great Barrier Reef across a wider range of geomorphic zones and conduct a more intensive study on a specific island group. This is of special importance noting the rate of declines reported by De’ath et al’s (2012) study which noted a 50% decline in coral reef cover since 1986 with a rate of decline of around 1.12% (p 17997) in the southern regions per year. Other studies such as those done by Bruno and Selig as referred to by Sweatman, Delean, and Syms (2011, p 524) considered the rate of decline between 1968 and 1983 to be around twenty five percent or 1.7 percent per year. To follow we will cover the general nature of the changes noted in coral cover followed by the distribution of the scale of these changes. The section after that will cover the changes in coral cover per reef and per geomorphic zone, as well as any broader spatial trends that can be seen with a section on sources of human error to conclude.

Considering the existing literature’s findings in terms of rates of coral decline the heterogeneity of these results is somewhat surprising. Of the four hundred and sixty five points for which change analysis was conducted eighty two of these points or 18% showed a decline, seventy five additional points or 37% showed no growth and two hundred and eight points or 45% showed a measure of growth as seen in Figure 7. Whilst these results may appear to go against existing literature such as De’ath et al, 2012 this graph does not show the scale or distribution of the changes which agree with existing literature and instead serves to show the direction of change regardless of the sample location. Considering the low proportion of growth points, the faster rate of temperature rise in the southern Great Barrier Reef (Woolridge, et al. 2010, P 952) and the decreasing rates of calcification due to rising acidity (Shaw. Et al, 2011, P 12); it would appear that corals ability to continue reef accretion and calcification is being damaged. This combination of pressures is expected to amplify existing sources of stress and possibly lead to the more resilient sections of the reef beginning to deline (Ban, et al. 2014, P 688).

In terms of averages, the mean increase in coral cover considering all geomorphic zones was found to be 15 percent with the average decline from Figure 8 being a decline of 25 percent. When combined these rates give a net rate of decline of -0.8 percent a year as opposed to the rate of decline reported by De’ath et al’s (2012) rate of 1.12 percent per year in the southern great barrier reef.

These results, however, are not to be considered without their spatial context both in terms of the reefs themselves and in terms of the Capricorn Bunker Group as a whole. Whilst Figures 7 and 10, and tables 14 and 15 may show most of the reefs are experiencing some measure of growth a quick examination of Figures 13 and 14 will show that it is the reef flats and lagoons which are the areas experiencing the growth. These results are somewhat balanced when it is remembered that most of the corals are located on the reef front (Geister 1977, P 26 – 27) where the largest losses were sustained and where the bulk of corals on a coral reef are located. Additionally the change analysis results from the lagoon geomorphic class whilst
still valid was based on a comparatively low number of samples as for the other classes as seen in Table 15.

In terms of the change analysis results per geomorphic zone Figure Ten and Table 15 illustrate the trends apparent in our data. Fore reefs experienced the greatest number of losses as well as the largest losses sustained. In contrast to this, reef flats and lagoons experienced some growth relative to the 2001 base level. It is to be noted however, that this does not imply a net growth in coral cover as corals are not even distributed across coral reefs. It should also be remembered that these geomorphic zones have differing environmental characteristics such as energy regimes to that of the fore reef and their corals must also deal with varying temperatures, daily tidal regimes, and PH levels (Kleypas et al, 1999). The isolation of lagoons by the tidal regime also influences salinity in addition to the Ph. As such the corals located in these geomorphic zones are typically harder and more resistant to environmental pressures which may explain why they did not register declines to the same degree as the fore reef zone. These stressors would render the corals in those two sections of the reef more adaptable, due to their zooanthellae and growth forms, to further changes in those variables than the fore reef area which would not have had to adopt to such variable conditions which would be reflected in increased mortality rates and bleaching (Woolridge, et al. 2010, P 952).

Figure 12 is in accord with what has been said by Sweatman, Delean, and Syms (2011, p 524) who found that over the course of their study the typical sites of disturbance on coral reefs had shifted towards the outer reef. When compared to the background average Hard Coral Cover gains were typically located near areas of high coral cover historically whereas the losses were typically in areas of twenty seven percent or less. This would appear to imply a reduction in the ability of these areas to bounce back after disturbances well as contributing to an isolating effect in terms of reservoirs for coral recovery. Woolridge referring to Done et al, 2007 noted the decreasing interval between disturbance events which would add further pressure in addition to existing environmental stressors on the remaining high coral cover areas in terms of being able to recover themselves from disturbances and aid the smaller hotspots (Woolridge et al., 2010, p 946).

In contrast to the fore reef results presented in Figure 12 reef flat and lagoon results as shown in Figure 13 and 14 were primarily located on the northern side of a line stretching from North West Island down to One Tree Island. This could be taken to infer that increased coastal turbidity and sediment loads were affecting the growth of the reef flats and lagoons and amplifying existing stresses (Ban, et al., 2014).

Over the course of examining Figures 12 through 14 and the broader spatial scale results they present, it became apparent that the background hard coral cover average layer had several “islands” or hot spots of greater than thirty percent coral cover. Of the seven “Islands” or hot spots, the smaller hot spots to the north east, east and to the south were sites of decline in hard coral cover. Should this trend continue the smaller hot spots ability to self-recruit after disturbances could be affected possibly compromising their viability.
Human error will of course have affected the accuracy of the results produced. The two primary areas through which human error would have affected the results were in the capture of and processing of the data, and in the mapping of the geomorphic zones. Errors in the capture of the data would have been brought about by inherent inaccuracies in the measurement devices themselves, the GPS and sonar being two examples of tools used with known inaccuracies. Digitizing errors as well as those brought about by the interpretation of the geomorphic zones would have also affected the results. Additionally the subjective nature of the ground cover estimation would have also affected the results of the change analysis. Human error would have also affected the accuracy of the geomorphic class mapping and the subsequent change analysis due to spatial resolution constraints of the images. Some geomorphic zones were mapped on a subjective interpretation of the satellite images as the “fuzziness” brought about by the spatial resolution rendered it difficult to map these geomorphic zones directly.

Conclusion:
This study revealed the non-uniform nature of the changes that had taken place in the Capricorn Bunker Group benthic communities between the two surveys. Of the four hundred and sixty five survey points 82% of the points did not register a decline in hard coral cover, but either no change in coral cover or an increase. It is to be noted however that the points registering declines in cover typically experienced changes of a greater magnitude than the points which were found to have undergone growth over the survey period. At a broader spatial scale, additional trends became visible with reference to the three surveyed geomorphic zones and the averaged hard coral cover between the two field data surveys. The fore reefs experienced losses away from the coast, with the reef flats and lagoons being the inverse of this with their losses being located on the reefs closer to the coast and to the south. The averaged background layer revealed several hot spots of hard coral cover with the losses in hard coral cover being concentrated on the smaller hotspots possibly affecting their ability to recover post disturbance.

Considering the subject matter of the present study it would be appear rather prudent to propose several recommendations, to improve further research of a similar kind. The first of these recommendations is that future satellite images for DEM generation come from a single source. The reason for this recommendation being that images from certain satellites presented difficulties in processing requiring their substitution with backup images which were of a lower spatial resolution. This issue had the primary impact of reducing the accuracy of the subsequently produced DEM and the geomorphic zone mapping that followed.

The second recommendation pertains to the spatial distribution of the survey points. The Skewed spatial distribution of the benthic community survey points, insufficient amount of sampling in some geomorphic classes or complete absence would have impacted the accuracy of ground cover percentages and change detection results through the small sample size. On this note a data set of 1000 to 1500 points would give a more detailed sample of each of the geomorphic zones with the sampling points being equally divided between the zones. This projects survey point distribution was constrained by the 2001 survey and so meant that only the points that were in close proximity to their corresponding 2001 survey points could be
used. Taking into account depth constraints or other factors such as wave activity or tidal constraints, future ground surveys should aim to sample in a grip pattern with the columns and rows having set spacing or the grid squares having a set area. Additionally attempts should be made to sample every geomorphic zone.

The twelve year gap between surveys whilst illustrative of noting absolute change in the benthic communities between these two time points is unable to show how finer scale variation has taken place between these two points in time. Should future ground cover change analysis surveys be undertaken a greater temporal resolution of two to four years is recommended. Additionally data of water quality for the Capricorn Bunker group would be of great utility in determining the impact of ongoing coastal development and the role it has played and will continue to play in the benthic communities of the Capricorn Bunker Group (UNESCO 2014, P 4).

The final area of recommendations would be to use a differentiated GPS system for future surveys to ensure the overlap between future field surveys. The accuracy of the GPS unit used in the 2014 survey was ±3m. This was used alongside the field of view data from the 2001 survey to ascertain the theoretical overlap between the two field survey paths by comparing the GPS position from the 2014 survey against the field of view for the 2001 data points revealing an overlap of around 72% for the revisited sites.

**Key Findings:**

1. Most Benthic community points registered either no change compared to the baseline or some growth.
2. In terms of the size of the changes registered the larger scale changes were more commonly found amongst the areas experiencing declines.
3. Average loss was 25% with the average increase being around 15%. This breaks down to a yearly decrease rate for those areas experiencing declines of -2.1% per year and an averaged yearly increase rate for those areas undergoing growth of 1.25%.
4. In terms of geomorphic zones the fore reefs experienced most of the losses with the reef flats and lagoons experiencing most of the gains. This could be in part due to the hardier nature of the corals in the lagoons and reef flats.
5. At a broader scale the losses for the fore reefs were confined to the outer reefs with the losses for the reef flats and lagoons residing in the central and southern regions.
Appendix:

Spectral Bands of the satellite images used:

**World View 2:**

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal</td>
<td>396 nm - 458 nm</td>
</tr>
<tr>
<td>Blue</td>
<td>442 nm - 515 nm</td>
</tr>
<tr>
<td>Green</td>
<td>506 nm - 586 nm</td>
</tr>
<tr>
<td>Yellow</td>
<td>584 nm - 632 nm</td>
</tr>
<tr>
<td>Red</td>
<td>624 nm - 694 nm</td>
</tr>
<tr>
<td>Red Edge</td>
<td>699 nm - 749 nm</td>
</tr>
<tr>
<td>NIR – 1</td>
<td>765 nm - 901 nm</td>
</tr>
<tr>
<td>NIR - 2</td>
<td>856 nm - 1043 nm</td>
</tr>
</tbody>
</table>

*Figure 15: Band wavelengths for the World view two satellites. (World Vision 2, 2014)*

**GeoEye:**

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>450 - 520 nm (Blue)</td>
</tr>
<tr>
<td>Band 2</td>
<td>520 - 600 nm (Green)</td>
</tr>
<tr>
<td>Band 3</td>
<td>625 - 695 nm (Red)</td>
</tr>
<tr>
<td>Band 4</td>
<td>760 - 900 nm (Near IR)</td>
</tr>
</tbody>
</table>

*Figure 16: Band wavelengths for the Geoeye Satellite. (Landinfo, 2008).*

**Ikonos:**

<table>
<thead>
<tr>
<th>Band</th>
<th>Wavelengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue</td>
<td>0.445 – 0.516 nm</td>
</tr>
<tr>
<td>Green</td>
<td>0.506 – 0.595 nm</td>
</tr>
<tr>
<td>Red</td>
<td>0.506 – 0.595 nm</td>
</tr>
</tbody>
</table>

*Figure 17: Band wavelengths for the Ikonos Satellite. (Geoeye, 2006)*
References:


Australian Bathymetry and Topography Grid - 2009


against climate change: realizable local and global actions’, *Climate Change*. Vol 112, P 945 - 961.